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Tests of Flexural Strength of Concrete

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TESTS OF FLEXURAL STRENGTH OF CONCRETE

BY

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THESIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

OTTO ARTHUR DICKE

ENTITLED TESTS OF FLEXURAL STRENGTH OF CONCRETE

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

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PART 1.

INTRODUCTION.

Comparatively few tests have been made on the tensile strength of plain concrete. This property, however, should receive more attention as it is closely involved in the most common and the most dangerous type of failure of reinforced concrete namely, "diagonal tension". The tensile strength of concrete is usually estimated to be one-tenth to one-eighth of its compressive strength, although there is no fixed relation between the two. The character of the aggregate has probably a greater influence on the tensile strength of concrete than upon the compressive strength. The manner in which the concrete is made and mixed also effect the tensile strength. It has been suggested by Professor Talbot that the flexural test may be used as a means of measuring the ability of the concrete to resist diagonal tension under which stress reinforced concrete beams usually fail unless this stress is especially provided for by placing steel stirrups at both ends of thebeam. The writer has therefore undertaken this thesis to determine the value of flexural strength of plain concrete of different ages and of different mixtures. There were 92 tests made on beams 6 in. x 8 in. cross-section and 3 ft. 4 in. long. The tests were made at the University of Illinois under the direction of the Engineering Experiment Station, between February 22, 1908 and May 12, 1908, to determine the flexural strength of plain concrete.

The results of the tests were arranged with the view to ascertain the effect of differently proportioned aggregates and the effect of age upon the tensile strength of concrete.

PART 2.

THEORY AND AVAILABLE DATA.

In the calculation of the modulus of rupture the weight of the beam must be taken into consideration. The modulus of rupture was calculated by the flexure formula, $\frac{M}{S} = \frac{I}{c}$

where, M, bending moment due to load.

I, moment of inertia of the section.

c, distance from neutral axis to the extreme fiber.

S, modulus of rupture in pounds per square inch.

The tensile stress due to the weight of the beam was used as a constant because the beams varied but little in weight.

A sample calculation is given with a load of 3200 pounds, in a 3 foot span. One cubic foot of concrete weighs 150 pounds. The moment of a uniformly loaded beam is 1/8 W.1, w where,

$W = 150 \times 1 =$ pounds.

$l =$ length of beam in inches, $= 36$ inches.

moment $= 1/8 \times 150 \times 36 = 675$ lb. in.

$I = 256.$

$c = 4$ in.

$S = \frac{675}{64} = 10.5$ lb. per square inch.

The beam was loaded at the 1/3 points.

$M = \frac{3200}{2} \times 12 = 19200$ lb. in.

$S = \frac{19200}{64} = 300$ lb. per square inch.

10.5 300 = 310 lb. per square inch.

A general formula for this size beam is, $S = .937\ W$ 10.5, where S = modulus of rupture and W = load applied on beam

in pounds.

TABLE I.

Modulus of Rupture, pounds per square inch,

for different mixtures.

Mixture.	Age at Test, Days. 4	7	14	24	30	60	75	100
1-1-2		238	257			342	500	
1-1 1/2-3						340		
1-2-4	70	130	191	202	208	271		322
1-3-6						191		
1-4-8		103	189			153		
1-5-10						174		

The following table is taken from "A Treatise on Masonry Construction" by Professor Ira O. Baker, giving results of tests made by A. F. Bruce. The beams were 4 in. x 4 in. x 30 in. In most of the beams the mortar was made of pulverized sandstone and cement. The aggregate was generally sandstone but gravel and broken whinstone were also used. Table I. is taken from the thesis presented by William Hadden Richardson to the College of Engineering, University of Illinois, June, 1907, to be used in comparing results of tests in this thesis.

In each case the voids in the sand were filled with cement and those in the aggregate with mortar.

TABLE I-a.

Ref. No.	Composition. Cement.	Sand	Aggregate.	Modulus of rupture in pounds per sq. in. Age in days. 7	28	56	84	133	182	273
1	1	2	3	95	145	215	266	301	303	320
2	1	2 1/2	5	37	144	165	194	268	236	256
3	1	3	5		88	129	176	191	214	214
4	1	2 1/2	6		81	130	156	193	199	212
5	1	3	7	37	113	154	187	216	243	263

The results are tabulated in the order of the ratio of the cement to the total weight of the aggregate. Notice that the results in the last line are proportionally higher than those in the remainder of the table. This difference is probably due to the fact that the specimens of the first four lines were made with natural sand and stone while in those for the last line only crushed stone was used, for aggregate. This table shows that the richer concrete has the greater modulus of rupture and also that concrete increases rapidly in strength up to about sixty days and thereafter a more gradual increase in strength for an indifinite period.

The following table is taken from Bulletin No. 1 of the University of Illinois Engineering Experiment Station for September, 1904, and shows the strength of concrete in tension. The tests were made of beams 6 in. x 8 in. x 3 ft., and loaded at the 1/3 points.

TABLE 2.

Test No.	Age in days.	Mixture	Maximum Load lbs. per sq.in.	Remarks.
7	50	1-3-6	178	Bending at start.
3	60	1-3-6	160	Bending through.
13	84	1-3-6	170	" "
12	87	1-3-6	278	Little bending.

This table also shows that the strength of concrete increases with age.

The following table is taken from the Transactions of The American Society of Civil Engineers, December 19, 1899,

giving 10 results of tests made by Mr. H. Von Schon on Portland cement concrete beams 6 in. x 6 in. x 18 in. tested to destruction by flexure. The average age of beams was 60 days.

TABLE 3.

Ultimate Fiber Stress, pounds per square inch.

Kind of Stone.	Mixture	Number of Tests.	Modulus of Rupture pounds per square inch Average.
Sandstone	A	2	176
"	B	2	217
"	C	2	280
"	D	2	325
"	E	2	102
Boulder stone	A	2	326
" "	B	2	328
" "	C	2	373
" "	D	2	410
" "	E	2	330

Mixture.

A. 1 part cement, 2.4 parts sand, 5.3 parts stone.
B. 1 part cement, 2.4 parts sand, 4.8 parts stone.
C. 1 part cement, 2.4 parts sand, 4.4 parts stone.
D. 1 part cement, 2.4 parts sand, 4.0 parts stone.
E. 1 part cement, 0.3 lime, 3.1 sand, 5.3 stone.

The following tables for comparison of results are taken from Sabin's Cement and Concrete, pages 317 to 325. The test beams were 10 in. x lo in. x 4 ft. 6 in. They were stored in moist earth soon after making. The breaking load was applied at the center of the beam. The half beams were tested the same way if a twenty inch span could be obtained.

TABLE 4.

Number	Parts of sand to 1 of cement by weight.	Tensile Strength, lbs. per sq. in. at 3 yrs. 1 Mo.	Number of Tests. 4ft. 6in. span.	Age. 1 yr.	Mean.	Mod. of Rupt. lbs. per sq. in. 20 in. span. No of Tests.	Age. 2 yr.	Mean.
76-77	0	717	2	7 Mo.	593	4	10mo.	600
78-79	1	790	2	"	689	4	"	698
80-81	2	595	2	"	538	4	"	577
82-83	3	432	2	"	489	3	"	415
84-85	4	335	2	"	479	4	"	385
86-87	5	252	2	"	284	4	"	316
88-89	6	218	2	"	262	4	"	279

From the above results it can be seen that the tensile strength of the richer mixtures in pounds per square inch was g greater than the modulus of rupture. The strength of the 1-4 mixture is 55 percent of the strength of the 1-1 mixture. The decrease in strength due to the larger proportion of sand in the mortar is usually greater than the decrease in cost.

TABLE 5.

Variation in Quality of Sand for fixed

Quantities of Cement and Stone.

No.	Amount of mortar made as % of compacted stone.	Amount of rammed Concrete as % of compacted Stone.	Modulus of Rupture. lbs. per sq. in. 4 ft. 6 in. Span. No. Tests.	Age.	Mean.	20 in. Span. No. Tests.	Age.	Mean.
74-75	16	95	2	1yr. 8mo.	299	4	2yr.1mo.	295
72-73	24	101	2	"	335	4	"	303
70-71	32	104	2	"	324	4	"	354
68-69	42	110	2	"	322	4	"	321

Line one of this table shows that the voids of the stone were not entirely filled with mortar when only 16% mortar was used. Line two shows that the theoretical ideal mixture should contain about 24% mortar. This mixture would require a great deal of labor to fill all voids, and the cost of labor would more than off set the amount of money saved in cement.

TABLE 6.

Value of thorough Mixing.

No.	Mixing of Concrete.	Modulus of Rupture. lbs. per sq. in. 4 ft. 6 in. span. No. Tests.	Age.	Mean.	20 in. span. No. Tests.	Age.	Mean.
182-186	Turned once and back	2	1 yr.	290	4	21 1/2 mo.	373
183-187	Turned twice and back.	2	"	294	4	"	353
184-188	Turned three times and back	2	"	306	4	"	444
185-189		2	"	328	4	"	474

Comparing the concrete turned once or twice and with that turned three or four times and back it is seen that there was an increase of strength of about 18% in the better mixed concrete.

PART 3.

MATERIAL, TEST-PIECES, AND METHOD OF TESTING.

STONE.

The stone used was Kankakee limestone ordered screened through a one-inch screen and over a one-quarter-inch screen. The stone weighed 86 pounds per cubic foot and 44% voids as determined from 3 samples.

Table 7 gives the proportion of sizes as determined from 17 samples.

TABLE 7.

Diameter of Mesh in inches.	Percent Passing.
1 in. = 1.000 in.	100
3/4 in. = .750 in.	89.2
1/2 in. = .500 in.	54.7
3/8 in. = .375 in.	32.8
No. 3. = .174 in.	16.9
No. 5. = .091 in.	4.1
No.10. = .066 in.	2.5

Plate 1 is a curve showing the relation between the diameter of mesh in inches and the percent of stone passing through it. The determination of voids in the stone and sand was made by the following method. The material was poured slowly into the water so that no air remained in the voids.

SAND.

The sand used in these experiments was obtained from the Wabash River near Attica, Indiana. It contained 35% of

voids as determined from three samples. Table 8 shows the proportion of sizes as determined from the samples.

TABLE 8.

Mechanical analysis of Sand.

No. of Sieve.	Diameter in mm.	Percent passing.
3	4.417	99.2
5	2.320	89.0
10	1.690	64.7
12	---	57.8
16	1.080	49.9
18	0.684	39.0
20	0.490	21.6
40	0.324	11.8
50	---	5.1
74	0.225	2.6
150	---	0.46

Plate 2 shows the curve for the fineness of sand giving the relation between the diameter of mesh in mm. and the percent passing.

CEMENT.

The cement used in these tests was Chicago A-A portland, purchased from the Sheldon Brick Company of Champaign, Illinois. Table 9 shows the results of tests made on this cement.

TABLE 9.

Tensile Strength of Chicago A-A Cement

pounds per square inch.

	Neat		1-3 Mixture.	
	7 days.	28 days.	7 days.	28 days.
	811	833	227	307
	665	779	175	266
	732	857	192	318
	559	707	145	247
Ave.	692	794	185	285

The tests in Table 9 were made to determine the tensile strength of the cements. The test pieces were briquettes of the form recommended by the Committee of the American Society of Civil Engineers. The briquettes after being made were covered with a moistened cloth and left to set. After 24 hours they were placed in water for 7 and 28 days before they were tested.

TEST PIECES.

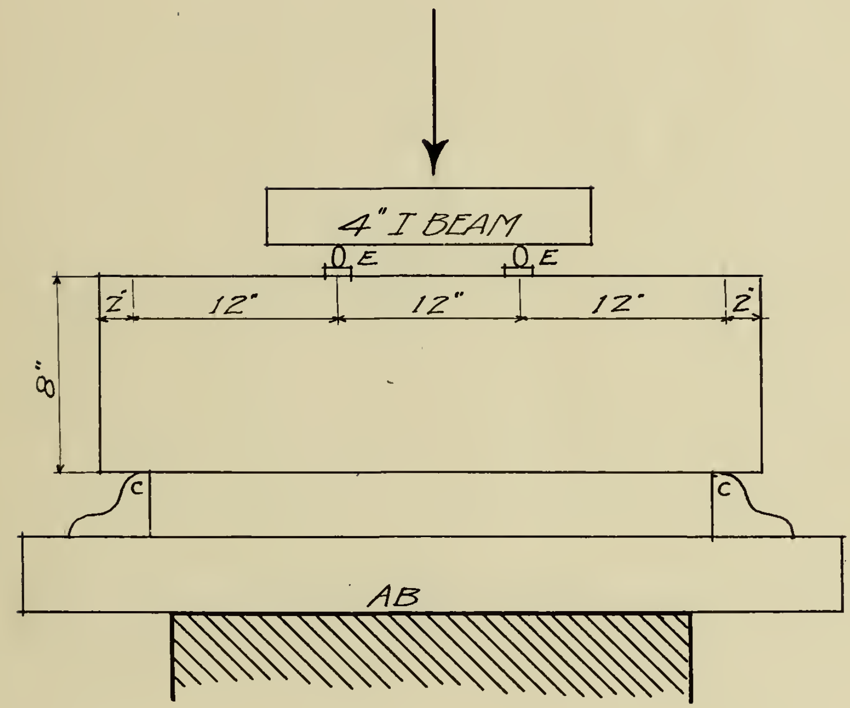
The beams tested were 6 in. wide 8 in. deep and 3 ft. 4 in. long. The beams were made in wooden forms which rested on a sheet of heavy building paper laid upon the concrete floor. The forms were made as shown in Fig. 1. All materials were measured by loose volume and were also weighed to check the measurements. All mixing was done by hand upon a steel mixing board by experienced men. The sand and cement were thrown upon the board and mixed dry until the color of the mixture was uniform. The stone and water were then added and the mass turned

twice. The stone was thoroughly wetted several days before using same. The concrete was placed into the forms in layers of 2 to 3 inches thick andeach layer thoroughly tamped. The sides were spaded with a trowel. The forms were left on the beams 7 days except in cases where tests were made at an earlier age than 7 days. The beams were sprinkled with water each day until tested so, as not to allow them to dry out too quickly. The beams tested for this thesis were made at the same time as the larger beams and T-beams of the same number described in other theses on reinforced concrete presented in the College of Engineering of the University of Illinois June, 1908. The beams were stored in the Concrete Laboratory where the temperature ranged from 55° to 65° F.

TEST OF BEAMS.

The beams were tested on a 100000-lb. Olsen testing machine with a speed of .02 inch per minute and on a 100000-lb. Riehle testing machine with a speed of .05 inches per minute. The beams were placed in the machine as shown in Fig. 2. Where the faster speed was used, a piece of soft wood was placed between the center knife-edge and the 4-in. I-beam. This piece of wood acted as a cushion and decreased the rate of application of the load.

FIG. 2



The support of the beam was on 3 in. x 8 in. x 4 ft. pine timber (AB) which rested upon the bed of the machine. The timber was carefully squared and planed. The beam rested on two supports (c) the tops of which were curved so as to give the beam a chance to deflect with out changing the length of the span. The load was transferred to the beam by means of a 4-in. I-beam resting on two 3/4 in. rollers (E). A bearing plate, 1 1/2 in. wide x 1/4 in. thick x 8 in. long was placed under the

rollers at E and these plates rested on two layers of building paper. The load was applied slowly and continuously to failure, only maximum loads were recorded.

PART 4.

DISCUSSION.

Table 10 gives the average modulus of rupture for the different proportions for different age of test.

TABLE 10.

Modulus of Rupture for different Mixtures.

Mixture.	Age at Test. Days.						
	4	7	14	30	60	70	125
1-1-2			304		466	477	
1-1 1/2-3					386	406	
1-2-4	29	176	191	327	372	375	455
1-3-6					236	253	
1-4-8			97			161	
1-5-10					136	149	

This table shows that the concrete becomes stronger as it grows loder and that the increase takes place more rapidly between the age of one day and 60 days. It also shows that the 1-4-8 and 1-5-10 mixtures are very weak in tensile strength. Plate 3 shows the relation between the modulus of rupture and age in days for the different mixtures.

Comparing the results in Table 1 and the results in Table 10 we find that the 60 day tests of this thesis have larger moduli of rupture with the exception of 1-5-10 mixture as shown in Table 11.

TABLE 11.

Mixture.	Age, 60days.	Modulus of Rupture in lb. per sq.in. Table 1.	Table 10.
1-1-2	"	342	466
1-1 1/2-3	"	340	386
1-2-4	"	271	372
1-3-6	"	191	236
1-4-8	"	153	
1-5-10	"	174	136

Comparing the results in Table 1 and to results in Table 10, we find that the 1-2-4 concrete in this thesis has a larger modulus of rupture than 1-2-4 concrete in Table 1.

TABLE 12.

Mixture. 1-2-4	Modulus of Rupture in lbs. per sq. in. Age in days.								
	4	7	14	24	30	60	70	100	125
Table 1.	70	130	191	202	208	271		322	
Table 10.	29	176	191		327	372	375		455

In each case the results of tests in Table 10, show a larger modulus of rupture with the exception of the 4 day test and the 14 day test.

Plate 4 is a diagram showing the relation between the modulus of rupture and weight ratio of the different mixtures. The weight ratio of the 1-1-2 concrete is 1-3.45, 3.45 is the sum of the weight of the sand and aggregate, considering the weight of the cement at 1.

There were six beams of the 1-1-2 mixture and the average proportion by weight of the sand and aggregate is 1.35

and 2.09 respectively. There were six beams of the 1-1 1/2-3 mixture and their average proportion by weight was 1:1.90:3.22.

There were forty-four beams of 1-2-4 concrete and the average proportion by weight was 1:2.52:4.18.

There were twenty-six beams of 1-3-6 concrete and the average proportion by weight was 1:3.76:6.34.

There were four beams of the 1-4-8 concrete and the average proportion by weight was 1:5.06:8.44.

There were six beams of the 1-5-10 concrete and the average proportion by weight was 1:5.96:9.81.

TABLE 13.

Parts by volume.	Parts by weight.
1-1-2	1:1.35:2.09
1-1 1/2-3	1:1.90:3.22
1-2-4	1:2.52:4.18
1-3-6	1:3.76:6.34
1-4-8	1:5.06:8.44
1-5-10	1:5.96:9.81

Table 10, the 70 day tests show the following results.

1:1 1/2:3 concrete was 85 per cent that of 1:1:2.

1:2:4 concrete was 78 per cent that of 1:1:2.

1:3:6 concrete was 53 per cent that of 1:1:2.

1:4:8 concrete was 34 per cent that of 1:1:2.

1:5:10 concrete was 31 per cent that of 1:1:2.

Table 10, the 60 day tests show the following results.

1:1 1/2:3 concrete was 84 per cent that of 1:1:2.

1:2:4 concrete was 78 per cent that of 1:1:2.

1:3:6 concrete was 50 per cent that of 1:1:2.

1:4:8 concrete was per cent that of 1:1:2.

1:5:10 concrete was 29 per cent that of 1:1:2.

Per cent of cement by weight in each concrete.

29 per cent cement in 1:1:2 concrete.

19.5 per cent cement in 1:1 1/2:3 concrete.

15.0 per cent cement in 1-2-4 concrete.

9.9 per cent cement in 1-3-6 concrete.

7.4 per cent cement in 1-4-8 concrete.

6.3 per cent cement in 1-5-10 concrete.

Taking the amount of cement in the 1:1:2 concrete as unity and the modulus of rupture 477, the following comparison was made.

TABLE 14.

Mixture	Cement by Weight.	Modulus of Rupture lbs. per sq. in. times ratio of cement.	Actual Modulus of Rupture lbs. per sq. in.
1:1:2	1.00	477 x 1 = 477	477
1:1 1/2:3	0.672	477 x .672 = 320	406
1:2:4	0.517	477 x .517 = 246	375
1:3:6	0.341	477 x .341 = 163	256
1:4:8	0.255	477 x .255 = 121	161
1:5:10	0.220	477 x .220 = 115	149

The above table shows that if the beams were made under exactly the same conditions the modulus of rupture of the different concretes would come close to those given in the 2 nd. last column provided 477 was the exact modulus of rupture of the 1:1:2 mixture.

TABLE 15.

Beam No.	Ultimate load in pounds.	Age in days.	Modulus of Rupture.	Mixture by Volume.	Mixture by Weight.
210.2	5900	71	553	1-1-2	1:1.27:2.11
342.2	4280	70	401	1-1-2	1:1.35:2.17
210.3	4160	60	390	1-1-2	1:1.18:2.08
341.2	3250	14	304	1-1-2	1:1.23:2.16
342.1	5510	62	517	1-1-2	1:1.71:1.87
210.1	5240	61	492	1-1-2	1:1.33:2.18

TABLE 16.

Beam No.	Ultimate load in pounds.	Age in days.	Modulus of Rupture.	Mixture by Volume.	Mixture by Weight.
211.4	4210	68	395	1-1 1/2-3	1:1.90:3.15
211.5	4770	71	448	1-1 1/2-3	1:1.93:3.20
130.7	3680	64	345	1-1 1/2-3	1:1.84:3.11
130.8	4000	71	375	1-1 1/2-3	1:1.91:3.24
132.6	2135	77	200	1-1 1/2-3	1:1.91:3.24
130.6	4560	63	427	1-1 1/2-3	1:1.95:3.40

TABLE 17.

Beam No.	Ultimate load in pounds.	Age in days.	Modulus of Rupture.	Mixture by Volume.	Mixture by Weight.
217.1	2420	15	225	1-2-4	1:2.55:4.15
217.2	3210	67	301	1-2-4	1:2.55:4.15
217.4	4680	87	439	1-2-4	1:2.61:4.32
218.1	3550	70	333	1-2-4	1:2.59:4.20
218.2	4500	61	422	1-2-4	1:2.59:4.22
220.2	4550	72	427	1-2-4	1:2.54:4.25
220.5	2590	67	243	1-2-4	1:2.66:4.43
221.3	3970	60	372	1-2-4	1:2.39:3.98
221.4	4990	71	468	1-2-4	1:2.20:3.98
229.1	4270	63	400	1-2-4	1:2.42:4.12
229.2	4500	65	422	1-2-4	1:2.53:4.06
252.6	4810	72	452	1-2-4	1:2.54:4.25
253.5	3900	59	365	1-2-4	1:2.63:3.71
240.1	3760	64	352	1-2-4	1:2.46:4.05
240.2	3430	66	321	1-2-4	1:2.65:4.38
256.1	5250	64	492	1-2-4	1:2.63:4.39
256.2	3000	64	281	1-2-4	1:2.54:4.25
331.1	310	3	29	1-2-4	1:2.34:4.04
331.2	2580	66	242	1-2-4	1:2.45:4.05
331.3	1500	11	140	1-2-4	1:2.47:4.21
333.1	1670	17	157	1-2-4	1:2.60:4.30
333.2					
332.1	2270	7	213	1-2-4	1:2.41:4.14
334.1	3110	33	292	1-2-4	1:2.55:4.15
334.2	3680	29	345	1-2-4	1:2.60:4.25
334.3	3680	29	345	1-2-4	1:2.48:4.18
		69			
522.1	4750	69	445	1-2-4	1:2.44:4.15
322.6	1980	377	186	1-2-4	1:2.22:3.92
322.5	3720	385	349	1-2-4	1:2.60:4.25
B_1	3300	60	309	1-2-4	1:2.51:4.67
B_2	4780	60	448	1-2-4	1:2.51:4.67
B_3	4000	60	375	1-2-4	1:2.39:4.15
B_4	3620	60	340	1-2-4	1:2.39:4.15
B_5	3830	59	359	1-2-4	1:2.48:4.41

TABLE 17.

(Continued)

Beam No.	Ultimate load in pounds.	Age in days.	Modulus of Rupture.	Mixture by Volume.	Mixture by Weight.
B_6	4550	59	427	1-2-4	1:2.48:4.41
B_7	3580	66	336	1-2-4	1:2.22:3.98
B_8	3800	66	355	1-2-4	1:2.22:3.98
65	3640	73	341	1-2-4	1:2.46:4.13
70	2890	70	271	1-2-4	1:2.40:4.18
75	2650	70	248	1-2-4	1:2.40:3.99
85	4850	126	455	1-2-4	1:2.62:4.36
86	3130	64	293	1-2-4	1:2.41:4.11
50	3360	68	315	1-2-4	1:2.55:4.06
76	2940	64	276	1-2-4	1:2.41:4.07
87	2480	49	233	1-2-4	1:2.44:4.21

TABLE 18.

Beam No.	Ultimate load in pounds.	Age in days.	Modulus of Rupture.	Mixture by Volume.	Mixture by Weight.
130.2	2550	65	239	1-3-6	1:3.75:6.34
130.3	1680	71	157	1-3-6	1:3.59:6.26
131.2	1390	64	130	1-3-6	1:3.71:6.48
131.3	2940	64	275	1-3-6	1:3.66:5.89
131.4	2650	64	248	1-3-6	1:3.65:6.26
131.7	1760	69	227	1-3-6	1:3.70:6.36
131.8	1960	60	184	1-3-6	1:4.11:6.84
131.9	2930	59	274	1-3-6	1:3.48:6.04
132.1	3930	63	369	1-3-6	1:3.36:6.32
132.2	3130	59	299	1-3-6	1:3.50:5.88
132.5	2980	67	279	1-3-6	1:3.94:6.70
134.1	2420	69	227	1-3-6	1:3.70:6.36
136.1	3050	60	286	1-3-6	1:3.67:6.44
136.2	1930	60	181	1-3-6	1:3.83:6.14
213.3	2100	66	197	1-3-6	1:3.93:6.57
213.4	3000	68	281	1-3-6	1:3.42:5.70
137.1	2650	63	248	1-3-6	1:4.04:6.59
137.2	1800	60	169	1-3-6	1:3.82:6.43
137.5	2560	63	240	1-3-6	1:4.21:6.48
137.6	1750	60	164	1-3-6	1:3.70:6.26
133.1	2860	59	268	1-3-6	1:3.53:6.12
135.2	2330	56	218	1-3-6	1:4.01:8.45
134.7	2210	51	207	1-3-6	1:3.46:6.03
135.1	1840	60	172	1-3-6	1:4.06:6.22
134.2	2230	60	209	1-3-6	1:4.03:6.24
134.6	1600	64	150	1-3-6	1:3.97:6.41

TABLE 19.

Beam No.	Ultimate load in pounds.	Age in days.	Modulus of Rupture.	Mixture by Volume.	Mixture by Weight.
214.3	1950	67	183	1-4-8	1:5.18-8.53
214.4	1490	70	140	1-4-8	1:4.83:8.23
351.2	1040	14	97	1-4-8	1:5.16:8.59
352.1	2390	62	224	1-4-8	1:5.08:8.41

TABLE 20.

Beam No.	Ultimate load in pounds.	Age in days.	Modulus of Rupture.	Mixture by Volume.	Mixture by Weight.
215.5	1880	60	176	1-5-10	1:5.75:9.61
215.3	1410	79	132	1-5-10	1:5.75:9.61
215.4	1875	70	176	1-5-10	1:60.9:10.0
361.1	1850	70	173	1-5-10	1:5.46:9.16
362.2	940	70	88	1-5-10	1:6.25:10.11
363.1	1025	62	96	1-5-10	1:6.44:10.38

PART 5.

CONCLUSION.

Concrete, as it grows older increases in strength and this increase is very rapid between the age of 14 and 70 days, as is plainly shown in this thesis. In building construction this characteristic should always be taken into consideration, for many times the forms are removed before the concrete obtains its assumed strength and sometimes causes serious accidents.

This thesis also shows that the richer mixtures of concrete are the stronger ones.

In many specifications for concrete work the mixture desired is simply specified as 1-2-4, one part cement, 2 parts sand, and 4 parts of some aggregate as crushed stone or gravel. This is a very indefinite statement as the cement may be measured in loose or compact form. In order to avoid dispute the proportion by weight should also be stated.

The proportions by weight of the 1-2-4 concrete and the 1-3-6 concrete of this work could be used, for the average of 25 and 50 tests can be taken as very nearly correct for the material anc conditions described.

FIG. I

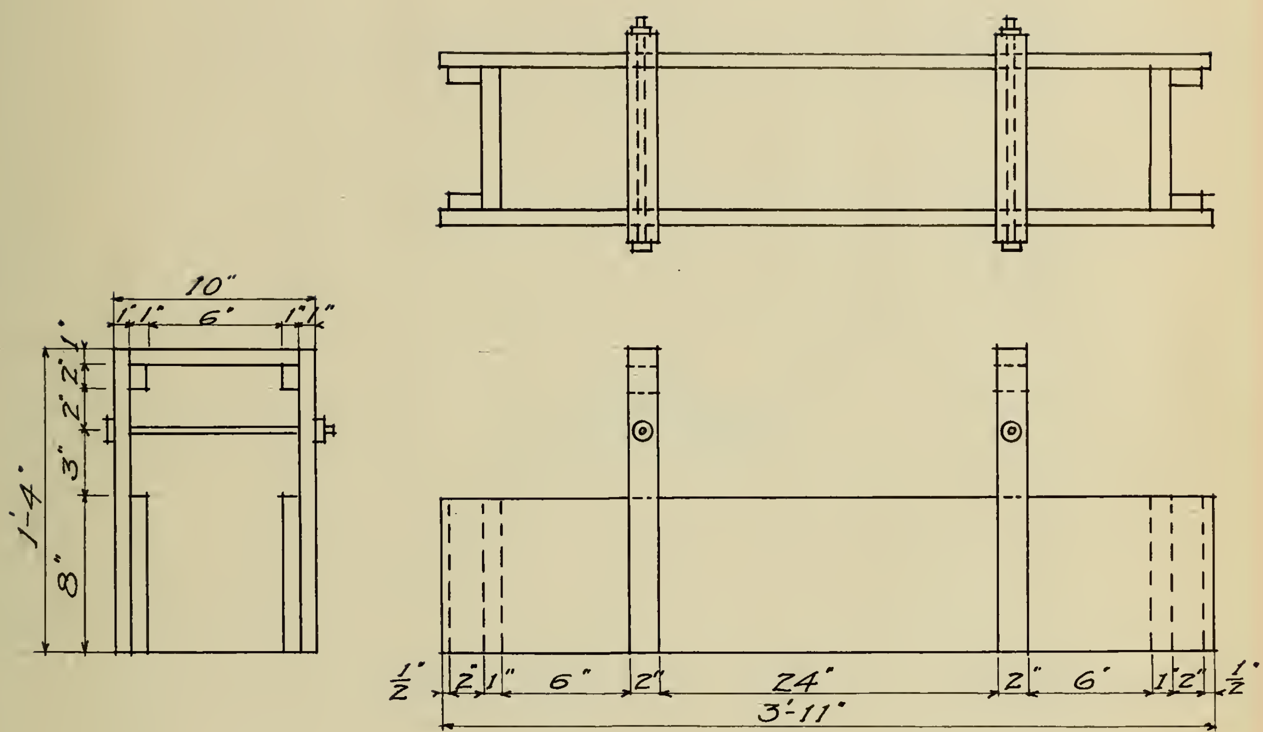


PLATE 1

DIAGRAM for PROPORTION of STONE

Showing Relation Between Percent through and diameter of Mesh in inches

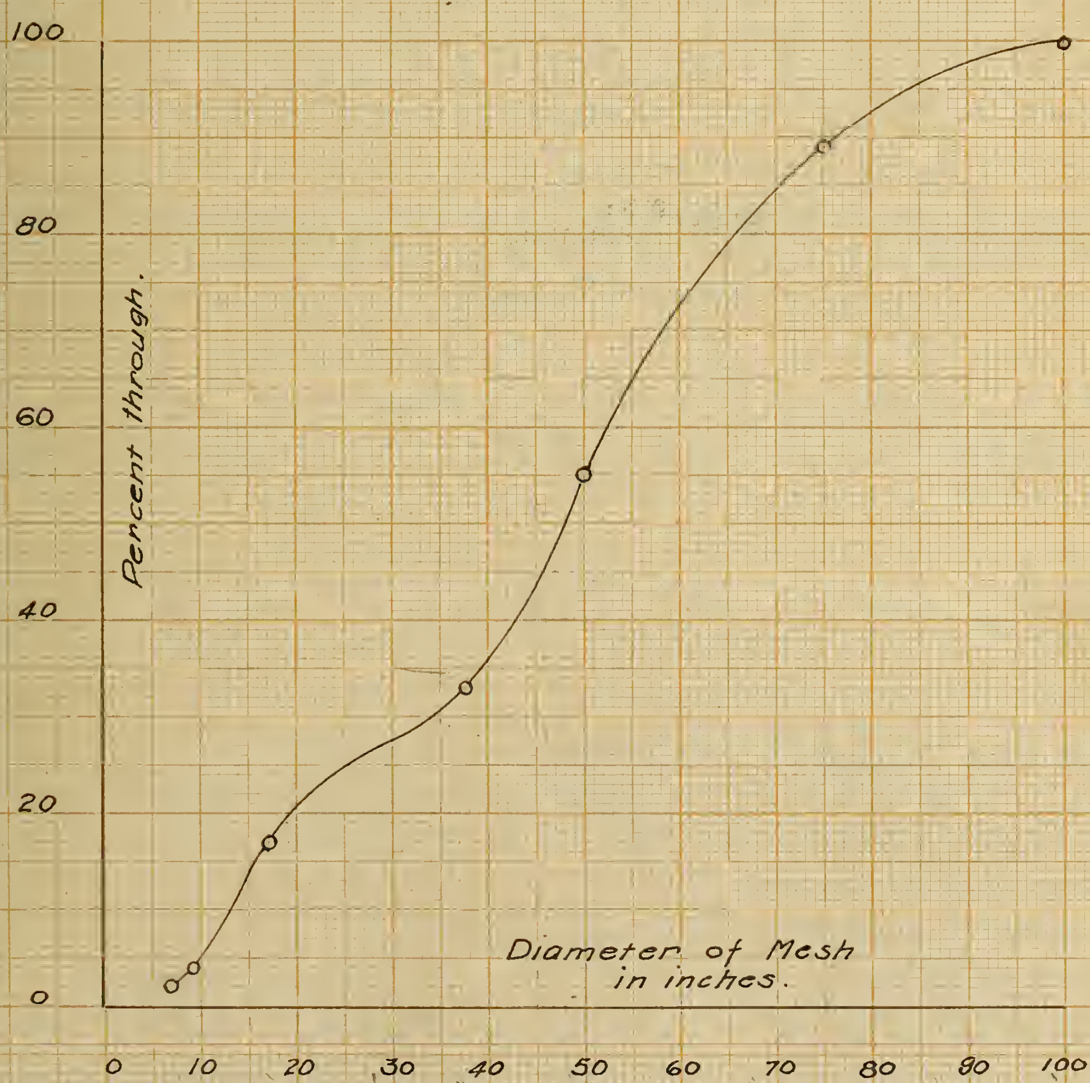
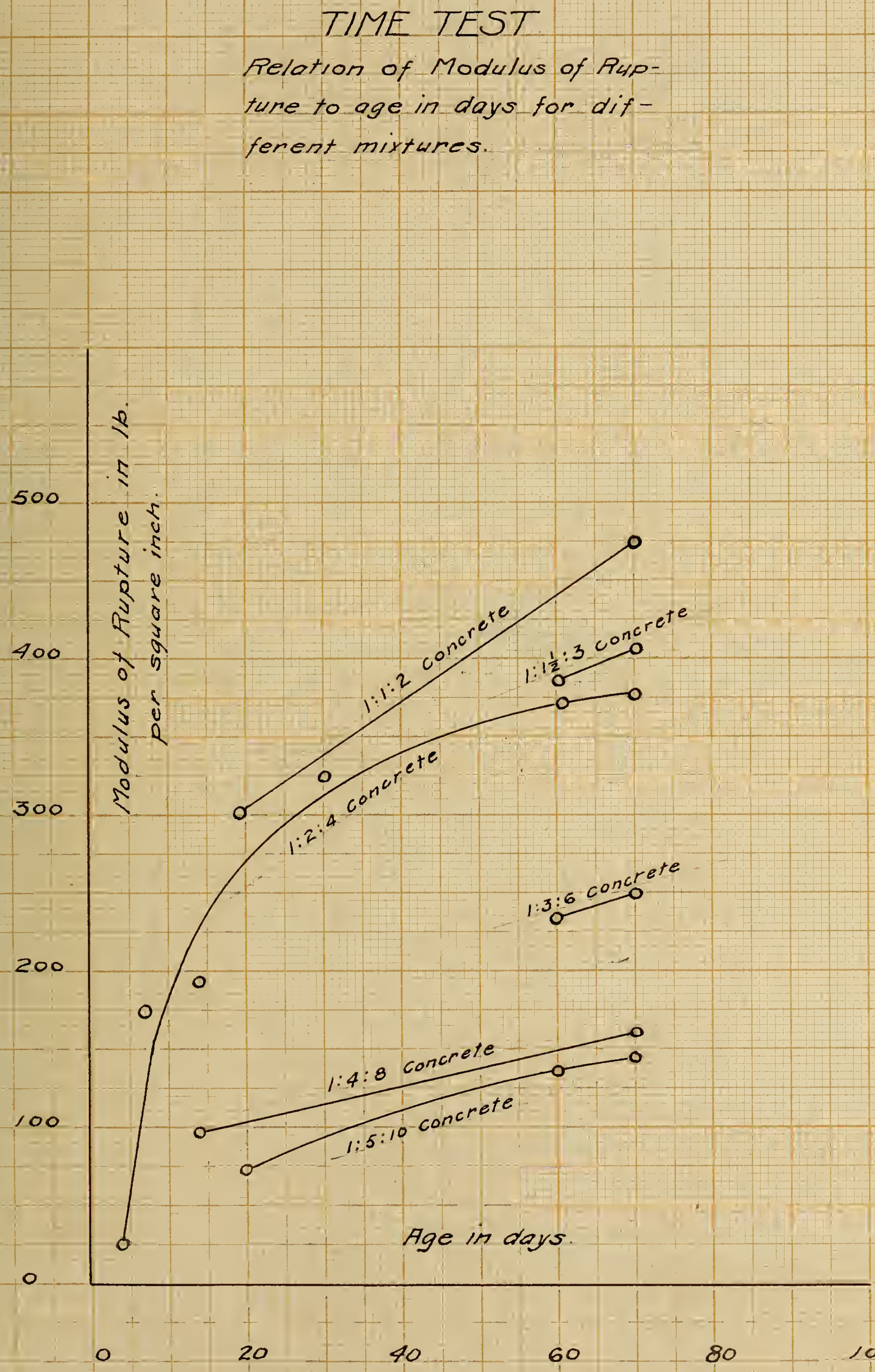


DIAGRAM for FINENESS of SAND

Showing Relation Between Percent through and size of Mesh in square mm.

PLATE 3.



TIME TEST
Relation of Modulus of Rupture to age in days for different mixtures.
Modulus of Rupture in lb. per square inch.
500
400
300
200
100
0
1:1:2 Concrete
1:1½:3 Concrete
1:2:4 Concrete
1:3:6 Concrete
1:4:8 Concrete
1:5:10 Concrete
Age in days.
0
20
40
60
80
100

DIAGRAM

Showing the Relation Between the Modulus of Rupture and the ratio by weight of the aggregate to the cement.